Effective Gob Well Flaring

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Currently, over 30 U.S. coal mining operations employ a system of degasification to assist in reducing the emission of methane into their mine ventilation systems. All of these mines use vertical gob wells. This is an effective gob degasification technique for U.S. longwall coal mining operations, particularly when prime movers apply suction to the wellheads (active gas extraction).

Under ideal conditions, operators collect gob gas (methane in air mixture) directly at the wellhead for sale or on-site use. However, because of vertical gob well gas production characteristics (variable gas quality and quantity), difficulties in coordinating commercial gas recovery with underground mine degasification requirements, and because of the economics of commercializing gob gas, coal mine operators commonly vent gas from gob wells to the atmosphere. This practice raises safety and global environmental concerns, and wastes a potential resource.

This article presents a safe and controlled system of gob well flaring that would provide substantial global environmental benefits. It presents a conceptual design of a gob well flare that incorporates safety features and operating practices based on petroleum industry standards. It summarizes the safety benefits, the global environmental benefits, and the potential financial benefits to mine operators of application of this system in the U.S. In conclusion, it presents an actual application of gob well flaring at a mining operation in Australia.

INTRODUCTION

In the U.S., and throughout the world, a growing number of companies are looking at low cost or profitable means of lowering or offsetting their greenhouse gas emissions. Since the United States signed and ratified the Earth Summit Treaty in Rio de Janeiro, Brazil, the *Climate Change Action Plan* was developed to provide partnerships between industry and the government to identify and realize economically viable measures to reduce greenhouse gas emissions. The U.S. Environmental Protection Agency's (U.S. EPA) Coalbed Methane Outreach Program is one of these programs, and has focussed its efforts on identifying and working with the coal industry to develop profitable projects to use coal mine methane, a potent greenhouse gas, rather than venting it to the atmosphere and contributing to global climate change. However, without external incentives, it is not always economic to employ all of the gas coming from degasification systems, in particular the gob gas of compromised quality and significant flow fluctuations. In these cases, companies interested in realizing significant reductions in greenhouse gas emissions could benefit from a low capital expenditure technology to combust this methane.

The U.S. EPA commissioned a conceptual design of a single gob well flare to constructively engage labor, industry and regulatory entities on the safety, technical, and cost aspects of constructing and operating a flare at an active gob well. Additionally, the U.S. EPA has been corresponding with technical experts in Australia regarding their experience with flaring, and the benefits that Australian coal mines have realized through their recent activities. Now the U.S. EPA seeks to help develop, in partnership with industry and labor, a demonstration facility in the U.S.

BENEFITS OF METHANE FLARING

Gas flaring is a standard safety practice in many industries. For example, methane and other associated gasses are routinely flared during processing and production of oil and gas, and are continuously flared from landfill collection systems. The petroleum industry flares for safety reasons during system upsets when high concentrations and volumes are released in the vicinity of potential sources of ignition. In the landfill industry, methane contributes to approximately 50 percent of the gas recovered. Flaring is conducted to combust it and other associated toxins (hydrogen sulfide and non-methane organic compounds) which are ground-level ozone build-up gases. Unlike landfills, coal mine gob gas consists of a methane mixture in air and does not contain many toxins.

Mine Benefits

Incorporating a controlled flaring system at gob wells would minimize the potential of an unconfined deflagration occurring on surface at well discharge locations brought about by natural or man-made sources. An unconfined deflagration, under appropriate conditions, may lead to a confined deflagration or detonation which may propagate in processing pipeline, and potentially through gob wells to the mining horizon. Incorporating a controlled flaring system would minimize this risk to the underground mine and to the public.

Continuous monitoring provisions, necessary with a gob well flare, would provide uninterrupted records of gob well performance. These would be invaluable in comparing gob well production with underground conditions, investigation of mine incidents such as mine fan failures, changes to the ventilation system, or accidents. Currently most active gob wellhead installations in the U.S. do not use continuous monitoring equipment.

Controlled flaring would reduce background concentrations of methane and allow mine operators to locate mine intakes closer to production areas.

Environmental Benefits

As the global warming potential of methane is approximately 21 times that of CO_2 (over a 100-year time frame) (IPCC, 1996), combusting the methane released from vertical gob wells with a controlled flaring system would result in emission of a significantly less harmful gas. Assuming stochiometric combustion of methane in air, combusting methane through flaring releases 7.5 times less greenhouse gas than venting.

Methane also contributes to tropospheric ozone problems and harms vegetation at high concentrations. Flaring coal mine methane may also alleviate local air quality problems.

PROPOSED GOB WELL FLARE

A controlled flare system is proposed with flare flash-back prevention features, a prime gas mover, an elevated stack, a controlled pilot, and a continuous monitoring system. A concept design, suitable for demonstration to a single, actively extracted gob well is presented. The concept design is also suitable, with some modification, for connection to a multiple gob well gathering system.

Flare Design Parameters

The gob well flare concept design was derived for typical gob well performance characteristics.

<u>Methane Concentration.</u> The flare was designed for combustion of methane concentrations (in air) ranging from greater than 30 percent to 100 percent by volume.

<u>Gas Flow Rate.</u> The flare design was developed to accommodate a variable range of gas flows (methane and air mixture). Standard gas flows ranging from 0.007 m^3/s to 0.661 m^3/s (14 to 1400 scfm (20 mscfd to 2 mmscfd)) were specified.

<u>Gas Heating Values.</u> Flare performance was specified for gas heating values ranging from 11.17 MJ/m^3 to 37.3 MJ/m^3 (300 Btu/scf to 1000 Btu/scf).

Codes and Guidelines

Applicable codes and guidelines for utility, landfill, and flares used in the petrochemical industry were incorporated in the gob well flare concept design.

<u>40 CFR 60.18 General Control Device Requirements.</u> These are control requirements to achieve EPA air emission standards and specify:

- no visible emissions (except for 5 minutes every 2 hours);
- flame presence at all times when emissions are vented;
- minimum gas quality (7.5 MJ/m^3 (200 Btu/scf) - unassisted flare);
- maximum gas exit velocity as a function of flare type and gas quality (18.3 m/s (60 fps) unassisted, variable quality);
- flares must be monitored for design conformance;
- the pilot flame must be continuously monitored.

Industry Handbooks

Applicable guidelines were obtained from flare gas systems handbooks.

<u>Flare Height.</u> The height of the flare is based on ground level limitations of thermal radiation intensity. These are determined from maximum gas flows and heating values, including wind factors. Recommended limiting radiation intensities are:

- 1.4 kW/m^2 (440 Btu/hr-ft^2) for unlimited time exposure by personnel;
- 9.5 kW/m^2 (3000 Btu/hr-ft^2) maximum at base of flare;
- 4.7 kW/m^2 (1500 Btu/hr-ft^2) minimum fenced boundary limit;
- 2.4 kW/m^2 (750 Btu/hr-ft^2) maximum at property lines
- 4.7 kW/m^2 (1500 Btu/hr-ft^2) at digital equipment and controls.

<u>Noise.</u> Noise emissions result from combustion of the turbulent gas stream. The emitted decibel level is proportional to the second power of the quantity of the hydrocarbon burned. In populated areas, a closed flare system may be necessary to reduce noise emissions.

<u>Luminance.</u> Sufficiently mixed air and fuel gases will burn with a blue non-luminous flame. If insufficient mixing occurs, the flame will become luminous. Where luminance is a concern, an assisted, or closed flare system is recommended.

Recommended Petroleum Industry Flaring Practices

The petroleum industry provides guidelines for flare flash-back protection. Flare flash back protection is achieved by either (1) ensuring a minimum purge gas flow at all times out the stack, or (2) incorporating a passive protective system which mitigates air inflow into the top of the stack. These measures are recommended in addition to a liquid seal which effectively arrests flame and detonation propagation upstream of the flare stack.

<u>Purge Gas Requirement.</u> A purge gas flow prevents air from entering back down into the stack due to wind or thermal effects and potentially creating an explosive mixture.

<u>Gas Seals.</u> Gas seals, commonly denoted as fluidic, or diode seals, are recommended to reduce the purge gas volume flow requirements. These seals are typically comprised of stacked conical orifices installed inside the flare stack below the burner tip which impede vortex back-flow generated by wind or thermal effects.

Liquid Seal. With a liquid seal, the gas process stream is introduced via a header into a vessel typically containing an ethylene glycol - water mixture and discharged through a submersed perforated diffuser. With this system, the gas is released as a series of distinct bubbles with liquid intervals between them which ensures mitigation of flame propagation through the seal. Standards recommend a minimum liquid head of 0.15 m (0.5 ft) above the diffuser outlet. A maximum of .30 m (1 ft) is recommended as gas pulsation occurs at higher liquid levels. The total volume of fluid in the vessel must also be equivalent to a minimum of 3.05 m (10 ft) of the gas inlet line. Should a detonation occur in the stack, the detonation would displace a liquid volume into the inlet header, and provide a minimum ethylene glycol – water seal of 3.05 m (10 ft) in the line separating the flare from the rest of the system.

PROPOSED GOB WELL FLARE DESIGN

Figure 1 illustrates the gob well flare concept design. The design incorporates the initial gas processing equipment which is typically in place at an actively extracted gob well, a by-pass gas venting system, the flare with flare flash-back prevention features, and the monitoring and control system. The estimated capital cost of the proposed flare design is US $60,000.

Characteristics

Active Flare. The design incorporates a mechanical blower/exhauster, as is typically fitted to an equipped gob wellhead assembly, to maintain a positive gas pressure through the flare system.

Open Flare. The design employs an open flare, where gas is burned at the tip of an elevated stack at combustion efficiencies of 98 percent, rather than an enclosed ground-level flare. Enclosed ground-level flares are applied at some landfills and burn low quality gas more efficiently and emit less NO_X (suitable for use in EPA designated "ozone non-attainment areas"), but have higher capital and operating requirements.

Unassisted Flare. Because of the lower heat content methane and air mixture extracted from a typical gob well, an unassisted flare with continuous burning pilot would readily combust the gob gas without producing significant visible smoke.

Flare Tip Diameter. The concept design recommends a minimum flare tip diameter of 24 mm (approximately 8 inches) based on the expected gas flow range and the requirements of 40 CFR 60.18.

Flare Height. Based on a 4.7 kW/m^2 (1500 Btu/hr-ft^2) criteria at the base of the stack, the concept design specifies a 6.1 m (20 ft) overall stack height. The heat distribution profile at grade, based on worst case wind conditions, will establish the equipment (and well-head) to flare spacing.

Pilot System. The design incorporates a continuously monitored and operating pilot.

Safety Features

Isolation of Potential Sources of Ignition. The blower/exhauster and the by-pass vent are two potential sources of ignition within the flare system. As indicated on Figure 1, an in-line detonation arrester isolates the blower/exhauster from the gob well. This arrester stops low speed confined deflagrations and high speed and high pressure flame fronts (sonic detonation and overdriven detonations) travelling in either direction. This unit is manufactured of spiral wound crimped metal which provides flame quenching elements of appropriate lengths and materials to adequately absorb or dissipate heat and retard and quench propagating flame. Anticipated pressure losses for a 0.254 m (10 inch) diameter unit are 2.4 kPa (0.35 psi) for the largest flow specified for the flare system design.

An end-of line flame arrester is fitted on the vent by-pass discharge stack. This arrester incorporates a crimped stainless steel foil element to prevent flash back from unconfined deflagrations.

The flame arresters and their arrangement are typical of gob well installations equipped with blower-exhausting equipment.

Isolation of Potential Ignition from Flare. The proposed design mitigates the potential of flashback from the flare by incorporating (1) an active positive pressure system, (2) an API recommended fluidic seal, (3) an API recommended liquid seal, and (4) a monitoring and control system with valve and equipment activation capability.

The blower/exhauster is the prime mover of the gas through the flare system and maintains a positive pressure to the liquid seal at the base of the flare. The liquid seal acts as a damper maintaining constant back pressure on the system. A pressure sensor between the blower/exhauster and the liquid seal continuously monitors for positive pressure to detect blower/exhauster operation.

The flare stack is equipped with a fluidic seal which prevents inflow of air into the stack with gas flows as low as 4.0×10^{-4} m^3/s (0.75 scfm or 1.08 mscfd), well below the minimum design flow of 0.007 m^3/s (14 scfm or 20 mscfd). As indicated under Monitoring and Control, the system measures gas quality and flow rate and activates an alarm should flows drop below 0.009 m^3/s (20 scfm or 28.8 mscfd), and valves for by-pass mode should gas flows reach 0.007 m^3/s (14 scfm or 20 mscfd).

The flare stack incorporates an API recommended liquid seal at the stack base to stop a confined deflagration and/or a detonation from propagating upstream. Gas is bubbled through a perforated diffuser maintained at least 0.15 m (0.5 ft) below a water-ethylene glycol seal. A head tank provides a positive pressure supply of the water-ethylene mixture for the liquid seal. The flare's control system activates the inlet valve (V5) based on the indication of the water level sensor. A discharge valve is provided for manual activation (V6) should visual inspection detect excessive liquid levels.

Isolation from Natural and Man-made Sources of Ignition. The design proposes that the flaring facility be protected from vandalism and unauthorized entry with a 2.4 m (8 ft) high perimeter fence and appropriately protected from lightning by elevated perimeter static wires.

Monitoring and Control System

The concept design incorporates a continuous monitoring system with active control capability. Table 1 illustrates proposed sensor set points and system actions during normal flare operations.

Sensor	Settings	System Action
Gas Quality	@ 30% Methane in Air @ 25% Methane in Air Max @ 100% Methane in Air	Actuate By-Pass Mode, Alarm De-Energize Blower/Exhauster None
Static Pressure	Min @ 250 Pa (1.0 in. w.g.) Normal >1500 Pa (6.3 in. w.g.) Max @ 3250 Pa (13 in. w.g.)	Activate By-Pass Mode, Alarm Alarm if Below Activate By-Pass Mode, Alarm
Gas Flow	Min @ .007 m3/s (14 scfm) Normal > .009 m3/s (20 scfm) Max @ .66 m3/s (1400 scfm)	Activate By-Pass Mode, Alarm Alarm if Below Activate By-Pass Mode, Alarm
Liquid Level in Seal	Min @ .15 m (6 in.) > Discharge Normal .15-.23 m (6 – 9 in) Max @ .305 m (12 in) Above	Activate Supply Valve None Activate By-Pass Mode, Alarm
Flame Ionization	Pilot Flame not Detected Pilot Flame Detected	Ignite Pilot None

Table 1. Set points and system actions during normal flaring operations.

Sensors. Transmitting sensors monitor gas quality, static pressure, temperature and flow rate of the process stream, in addition to pilot operation. Analog output from the sensors are routed to a data logger with programmable activation and data recording features.

Control. Power is supplied to the blower/exhauster, all solenoid valves, and the pilot ignition system. At programmed sensor conditions, the data logger activates relays as appropriate. The design incorporates a cellular modem which provides for retrieval of performance data from any computer site.

Fail Safe Valves. The system design incorporates three principal compressed air activated fail safety valves (V2 through V4 as shown on Figure 1). Compressed air at 550 kPa (80 psi) is supplied by small diameter lines connected to a storage tank and integrated compressor. Manual and data logger activated solenoid valves are connected to the compressed air lines at the Valve Controls (Figure 1) to either bleed or provide positive air pressure to the actuators.

Control Solenoid Valves. Two additional solenoid valves are incorporated to activate the fuel gas supply (V7) and maintain fluid level control in the liquid seal at the base of the flare (V5).

Manual Operation Provisions. The system employs manual over-ride provisions, including sight monitoring gauges for pressure, gas flow and gas quality. Of particular concern during start-up of the system is ensuring sufficient gas flow through the stack prior to ignition of the pilot. Although this can be done automatically, the design recommends manual system re-activation when switching from by-pass to flare, and when initiating from the shut-in position.

EVALUATION OF POTENTIAL ENVIRONMENTAL AND ECONOMIC BENEFITS OF FLARING

Methane is a "greenhouse gas," meaning that its presence in the atmosphere affects the earth's temperature and climate system. Methane's chemically active properties have indirect impacts on global warming as the gas enters into chemical reactions in the atmosphere that not only affect the period of time methane stays in the atmosphere (i.e., its lifetime), but that also play a role in determining the atmospheric concentrations of tropospheric ozone and stratospheric water vapor, both of which are also greenhouse gases. These indirect and direct effects make methane a large contributor, second only to carbon dioxide, to potential future warming of the earth. Over a 100-year period it is 21 times more effective at trapping heat in the atmosphere than carbon dioxide. In 1996 178 Mt (196 mm tons) of carbon equivalent emissions (using a 100 year global warming potential) came from anthropogenic methane sources in the U.S., or over ten percent of total greenhouse gas emissions. Put in perspective, emissions of carbon dioxide attributed to the entire U.S. industrial sector totaled 466 Mt (514 mm tons).

In the United States, methane emissions from coal mines are the fourth largest anthropogenic source, after landfills, agricultural activities, and fugitive emissions from natural gas lines. EPA estimates that emissions in 1996 equaled 18.9 Mt (21 mm tons). Because coal mine methane is a valuable energy resource, its economic use should always be the first option to consider. However, in some instances this gas is either of too low a quality, or is too far from a market to make this choice viable. In these instances, flaring can be an attractive means of reducing greenhouse gas emissions at low cost. A single gob well flare, as described in this paper, allows for additional flexibility in destroying the particular gas sources that do not have a market. EPA estimates that of the 1.6 Gm^3 (57 bcf) of methane drained from U.S. mines in 1997, 1.2 Gm^3 (42 bcf) was used, leaving 425 Mm^3 (15 bcf) of vented gas (U.S. EPA, 1998). Assuming that 50 percent of this vented gas could not be viably employed, 121 M m^3 (7.5 bcf) of methane, or nearly 1 Mt (1.1 mm tons) of carbon equivalent emissions could be handled with flares.

The Value of Flaring to Coal Mine Operators

Flaring is a very cost effective means of reducing methane emissions. The expected average cost to reduce greenhouse gas emissions has become the subject of much debate. There is significant disagreement between economists on this question, with average cost estimates ranging from dollars per ton of carbon equivalent reductions to well over $180/t ($163/ton) (Yeller, 1998, and Mining Week, 1998).

Translated into methane volumes, \$10/t (\$9.07/ton) of carbon equivalent would equal \$38.85 per 1000 m^3 (\$1.10/mcf); \$50/t (\$45.36/ton) carbon would equal \$194.23 per 1000 m^3 (\$5.50/mcf) in the potential value of the emissions offsets. Brokers cite current trades of carbon emissions at around \$5.50/t (\$4.99/ton).

Economic Analyses

Preliminary after-tax economic analyses, performed for a range of average methane flow rates from a typical vertical gob well, determine the carbon equivalent break-even cost of flaring. These analyses assume:

- A installed cost of U.S. \$85,000 which includes project development, installation and permitting;
- An operating cost of U.S. \$17,000 per year which includes monitoring, maintenance, and relocation (assume once every two years);
- A twelve (12) year project life;
- Cost of capital of 15 percent;
- Inflation at 3 percent per year;
- Escalation in value of carbon of 6 percent per year (Natsource, 1999);
- An average annual tax liability of 40 percent.

Figure 2 presents the estimated discounted cost of gob well flaring on a value of carbon equivalent basis for average gob well methane flows of between 2,830 and 16,990 m^3 per day (100 and 600 mscfd) (averaged over one year). The figure illustrates that discounted costs are well below \$10/t (\$9.07/ton) of carbon equivalent for the average range of methane flows considered. The figure shows that flaring is economic for current carbon values of \$5/t (\$4.54/ton) with average daily methane flows of greater than 5,663 m^3 per day (200 mscfd). Estimated internal rates of return for a range of carbon values (\$1.83/t to \$7.33/t) and range of average methane flow rates are presented on Figure 3. The figure demonstrates that the return on investment may be significant for the values of carbon offsets discussed herein.

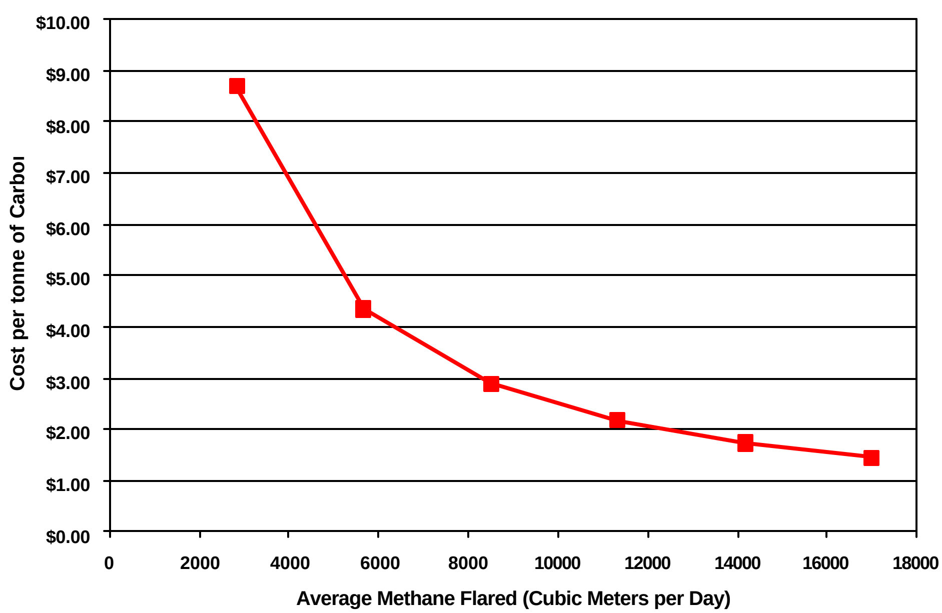

Figure 2: Discounted Break-even Cost of Flaring.

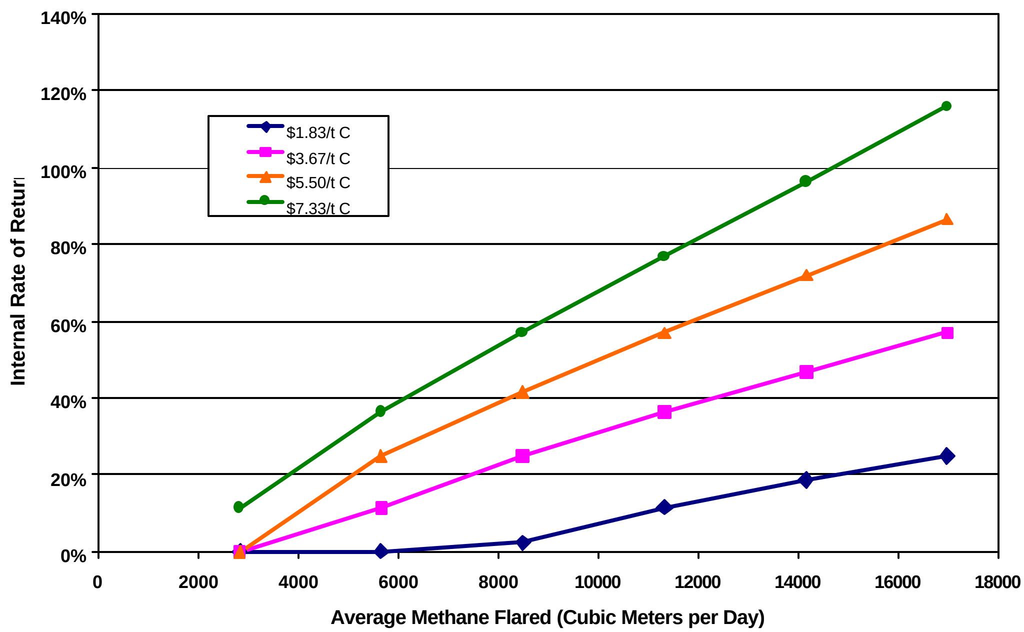

Figure 3: Internal Rate of Return for Flaring for a Range of Carbon Values.

GOB WELL FLARING EXPERIENCE TO DATE

Capricorn Coal Development Joint Venture (Capricorn) commissioned a gob well flare similar to the design presented herein at the Central Colliery in Queensland, Australia. Capricorn submitted a detailed design of the flare to Australian mine safety authorities for comments which were addressed by Capricorn to the satisfaction of the authorities. Capricorn constructed the flare and it became operational in December of 1998. The flare combusts methane from a number of vertical gob wells and is rated for 102,000 m^3 per day (3.6 mmscfd) of gob gas. Presently it combusts an average 90 percent methane and air mixture (by volume), and is reducing carbon emissions by more than 10,000 t (9,078 tons) per year (Shell Coal, 1999). As shown on Figure 4, the flare is 20 meters tall (65.6 ft). It implements a flame arrester below the flare tip for flare flash-back protection, as opposed to the liquid seal proposed in the concept design. It is continuously monitored, and is equipped with fail-safe controls that by-pass the flare during low gob gas flows, and alarm if high static pressures are monitored upstream of the flare. As of the date of this article, the flare has successfully operated as designed.

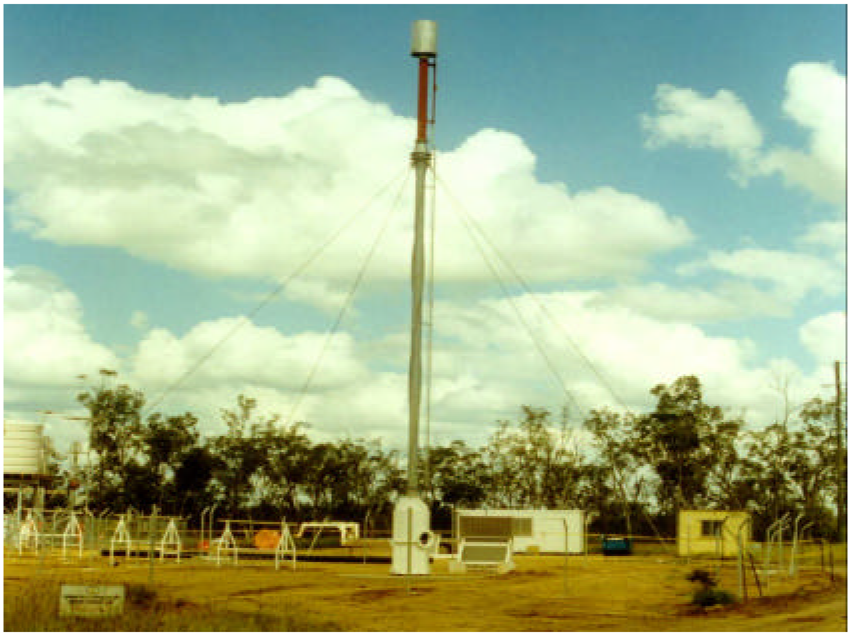

Figure 4: Gob Well Flare Commissioned by Capricorn at Central Colliery in the Bowen Basin.

CONCLUSION

While installation of the proposed flare design may bring significant economic, safety, and operational benefits to a coal operator, to develop a flare in the United States, any system will require the approval of the Mine Safety and Health Administration (MSHA). As such, the U.S. EPA has presented the gob well concept design to MSHA who indicated that a pilot flaring project would need to be approved at the district level upon request by a mine operator. The U.S. EPA is interested in partnering with mine safety authorities, coal operators, and labor to ensure that all real and perceived safety concerns are addressed in a demonstration project.

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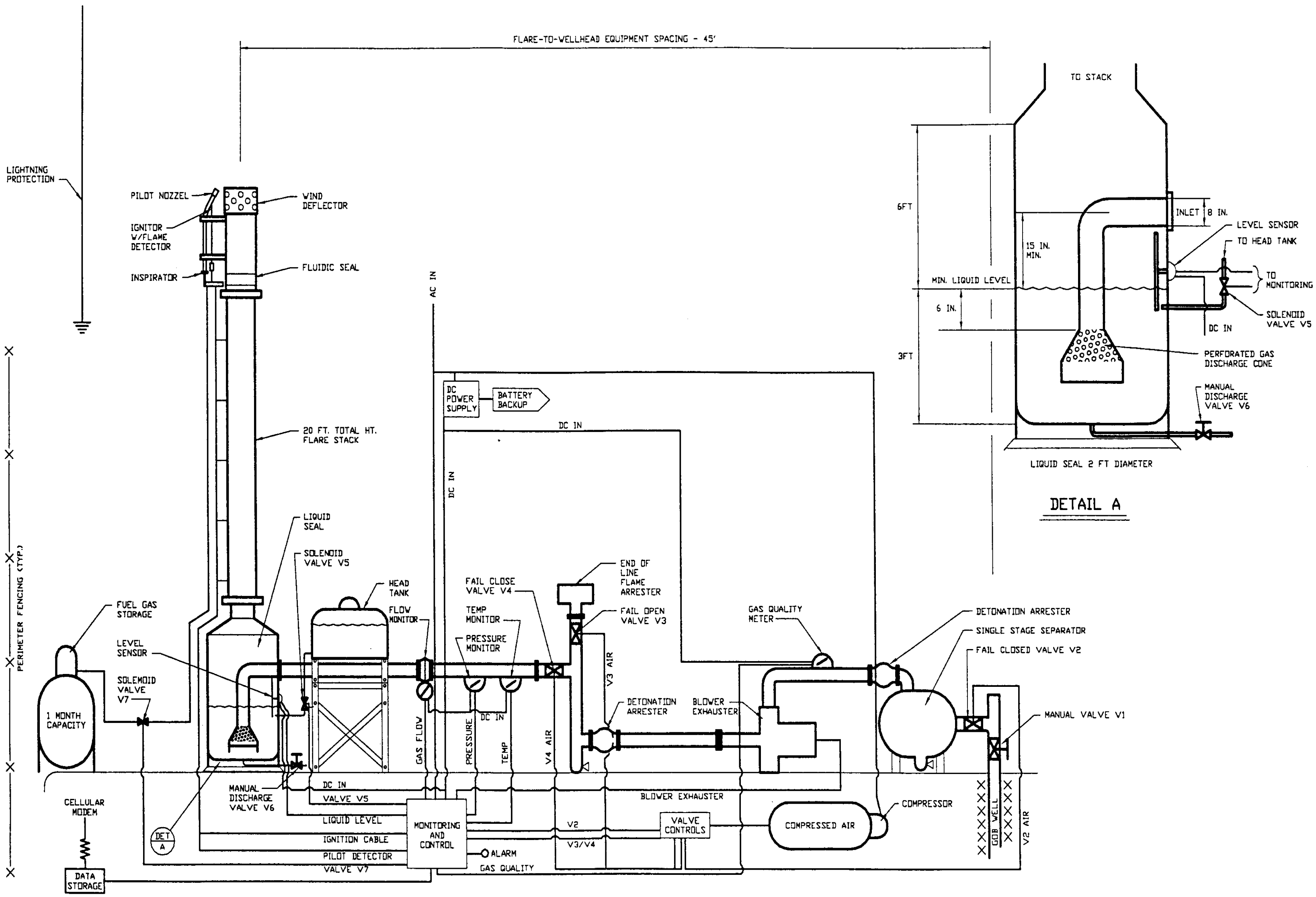

Figure 1: Conceptual Design of the Proposed Gob Well Flare.